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NEUTRON DOSIMETRY: A PIN DIODE READER

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INTRODUCTION

For clinical in vivo radiation dosimetry, passive radiation detectors are preferred to active ones because they are generally small and free of cumbersome cables. Typical active detectors are ionization chambers, proportional, Geiger and scintillation counters, and regular semiconductor diodes. Passive dosimeters include thermoluminescent crystals, photographic films, activation detectors, solid state nuclear track detectors and PIN diodes. Passive detectors may be introduced into body cavities (mouth, ear, nose, lung, stomach, rectum, vagina) with little discomfort to the patient. These detectors then may be used to check the accuracy of treatment planning calculations.

Neutrons with energies greater than 200 eV incident on Si crystal structures cause displacements of lattice atoms. These

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displacements are electron traps which in turn cause an increase in the resistance of the crystal. This resistance change is related to the neutron absorbed dose in the crystal. A graph of $\ln (V_f - V_i)$ versus fast neutron dose is nearly linear. For doses below about 6 Gy (6 joule kg^{-1}), the absorbed neutron dose is almost proportional to $V_f - V_i$. V_i , V_f are the voltage drops across the diode initially and after the irradiation. The voltage measurements must be made at constant current and temperature. The diodes should be stored and exposed at the same temperature to avoid unpredictable self-annealing. Finally, little energy should be deposited in the diode while the voltage drop is measured to avoid temperature rises that may also cause annealing.

Detailed discussions of the use of PIN diodes for neutron dosimetry have been given elsewhere¹⁻¹⁰ and in the references therein.

A PIN DIODE READOUT SYSTEM

A simple manual system to read the voltage drop across individual PIN diodes was built with the intention of minimizing heating by the testing current and providing accurate measurements of V_f and V_i .

Brief Circuit Description

The complete circuit block diagram is shown in Fig. 1. Three main functions are incorporated in the reader: (1) BLOCK A: precision constant current generator and switch. A1 is an operational amplifier. (2) BLOCK B: voltage monitoring, sample

and hold circuit (S&HC), and ADC/display unit. A2 is an instrumentation amplifier. (3) BLOCK C: timing circuits and trigger output.

1. The constant current generator has a range of 22 to 30 mA. A typical current for reading PIN diodes in neutron dosimetry applications¹¹ is 25 mA. This current is set by requiring a voltage drop of 1.000 ± 0.001 V with a 40.0 ohm resistor connected to the reader in place of a diode. The circuit maintains this value for many days to within ± 0.001 V, even if the power is turned on and off each day.
2. The voltage across the diode is sampled at the input by A2 which is followed by the S&HC. The output of the S&HC goes to the panel meter which has a built-in ADC. An external 1 MHz clock is needed for operation of the panel meter.
3. Timing circuits. The purpose of these circuits is as follows:
 - i. After a (push-button) request for a measurement, the current from the constant current generator is shifted from the FET transistor to the PIN diode.
 - ii. After a suitable delay (approximately 1 to 10 msec) the S&HC is turned from sampling to holding, the ADC/display is signaled to convert and display, and the current is shifted back from the diode to the FET transistor.

TESTING THE PIN DIODE READER

To test the performance of the instrument, measurements were made with a 40.0 ohm resistor and six model DN-156 PIN diode neutron dosimeters, manufactured by Harshaw.¹¹ Twenty-four hours before the measurements, the diodes were given doses of 1, 2, or 4 Gy using the p(66)Be(49) clinical neutron beam at Fermilab.¹² We were especially interested in determining if there would be any indications of annealing in the diodes when 20 readouts for each of the seven devices were made (in 12 minutes).

Results

The results of the measurements are shown in Fig. 2. The standard deviation of the readings is less than the diameter of the plotting symbols. The current pulse width was 10 msec for this evaluation.

For the 40.0 ohm resistor the average reading was 0.9986V, with a standard deviation of $\pm 0.0009V$. Discarding the first five readings of each PIN diode, regression analyses were made of the remaining 15 points. The results are given below.

| | | | |
|----------------------|---------|---------|--------------------|
| Diode No. | 4 | 5 | 6 |
| Dose (Gy) | 1 | 1 | 2 |
| First Reading (V) | 1.802 | 1.815 | 2.071 |
| y-axis Intercept (V) | 1.7919 | 1.8007 | 2.049 ₄ |
| Slope (V/reading) | -.00002 | -.00022 | -.00025 |
| Correlation Coeffic. | -.113 | -.658 | -.789 |

| | | | |
|----------------------|--------------------|--------------------|---------|
| Diode No. | 7 | 8 | 9 |
| Dose (Gy) | 2 | 4 | 4 |
| First Reading (V) | 2.076 | 2.704 | 2.727 |
| y-axis Intercept (V) | 2.043 ₁ | 2.629 ₄ | 2.651 |
| Slope (V/reading) | -.00028 | -.00051 | -.00039 |
| Correlation Coeffic. | -.715 | -.865 | -.835 |

As expected from Fig. 2, the scatter of the voltage measurements is comparable to the slope of V_f versus reading, therefore, the correlation coefficients are not close to -1. It is interesting that the slope seems to vary monotonically with V_f . It would seem that the more the crystal damage, the more the annealing that is caused by the testing current.

After the first five readings, the reading-to-reading fluctuation superimposed on the average slopes is of the order 1-2 mV. For the p(66)Be(49) clinical neutron beam, the conversion factor for $V_f - V_i$ at low doses (less than about 4 Gy) is about 0.4×10^{-2} Gy/mV. Hence, for the p(66)Be(49) clinical neutron beam it seems that PIN diode neutron dose measurements may be estimated to $\pm 0.8 \times 10^{-2}$ Gy. For reactor neutrons, the manufacturer¹¹ claims approximately twice as many Gy/mV. Of course, other factors such as diode history, annealing techniques, individual diode sensitivity and storage temperature may have more profound effects in dose estimates than the noise produced by the diode itself.

CIRCUIT SCHEMATIC AND COST

A complete circuit schematic is given in Fig. 3.

The cost of all the materials, including panel meter and NIM module, was approximately \$250.00. It took approximately 40 hours to build the unit.

CONCLUSIONS

This PIN diode reader causes very little annealing of diodes during readout. It is stable, easy to use, and relatively inexpensive to construct.

ACKNOWLEDGEMENTS

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LIST OF FIGURES

Figure 1 Block diagram of the PIN diode reader.

Figure 2 V_f versus number of V_f readings. The current pulse was 10 msec wide. The doses to the diodes were 1, 2, and 4 Gy.

Figure 3 Circuit schematic of PIN diode reader.

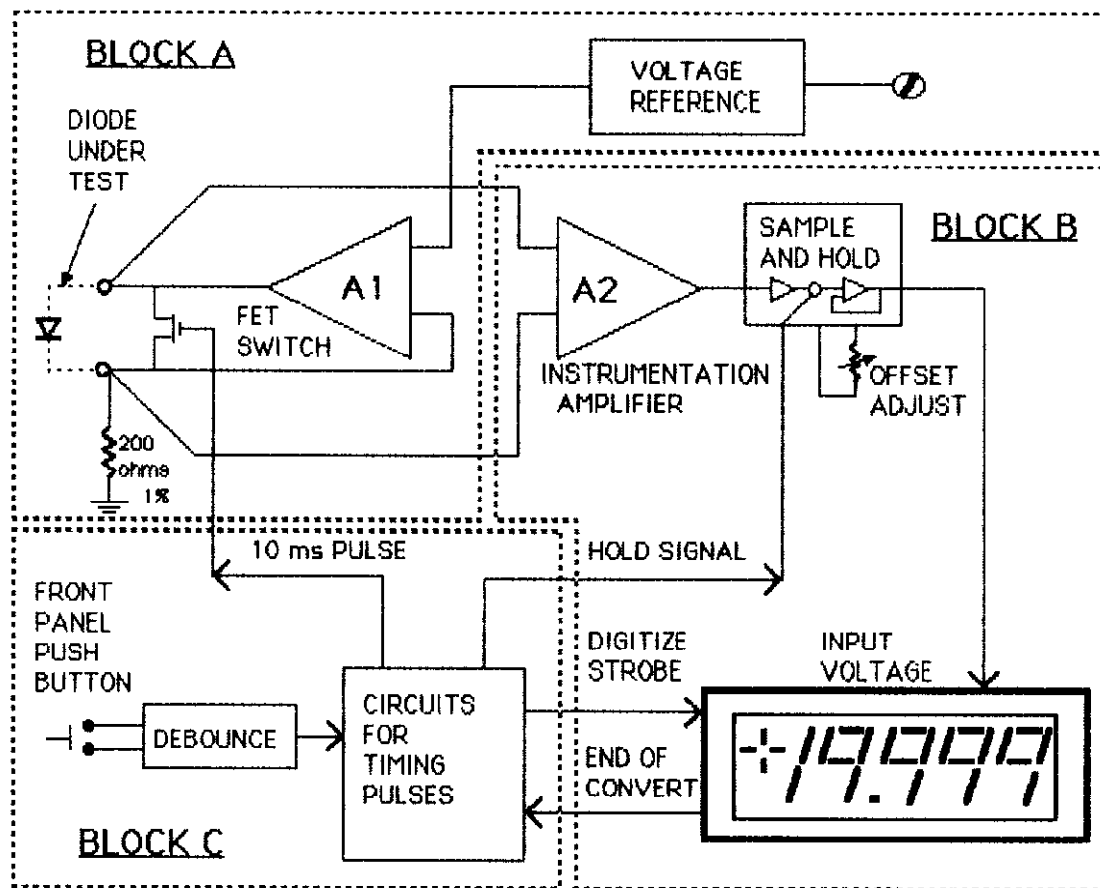


Fig. 1

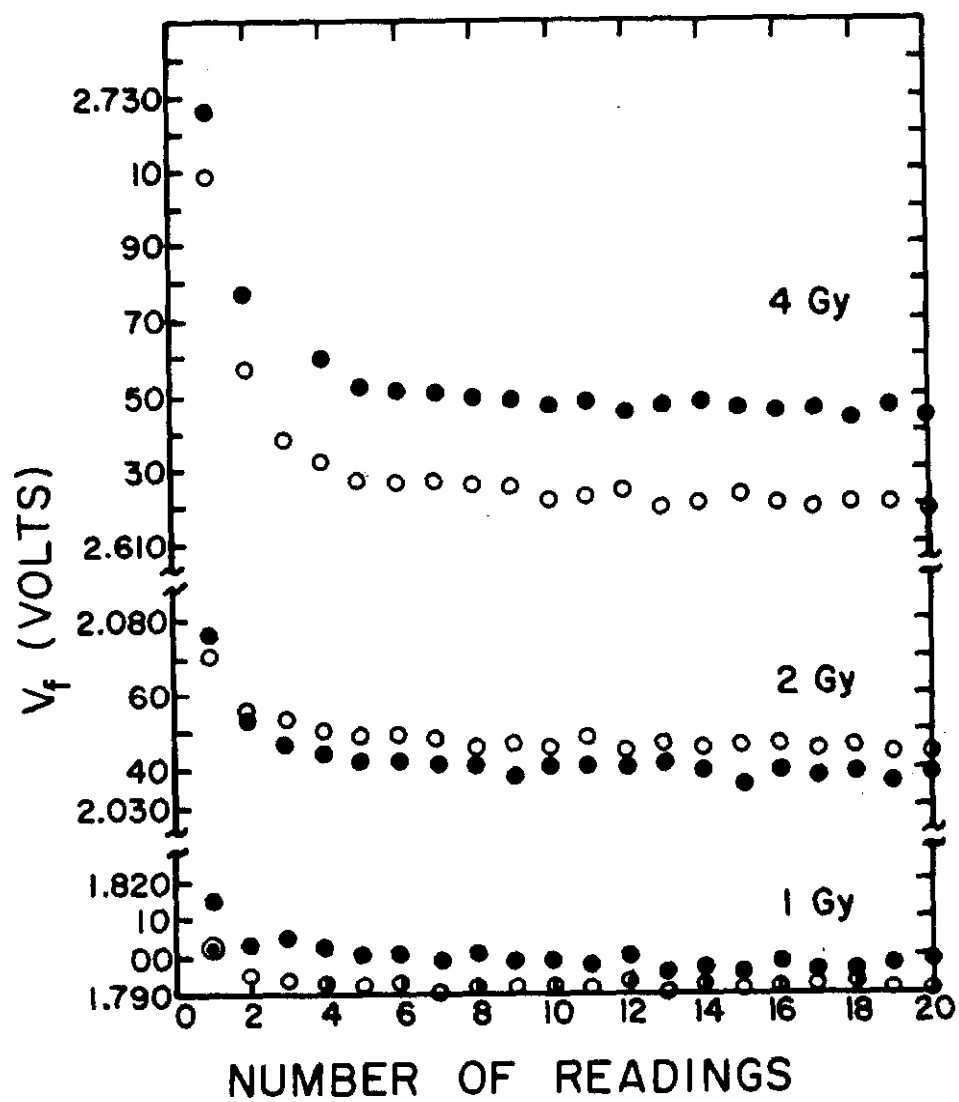


Fig. 2

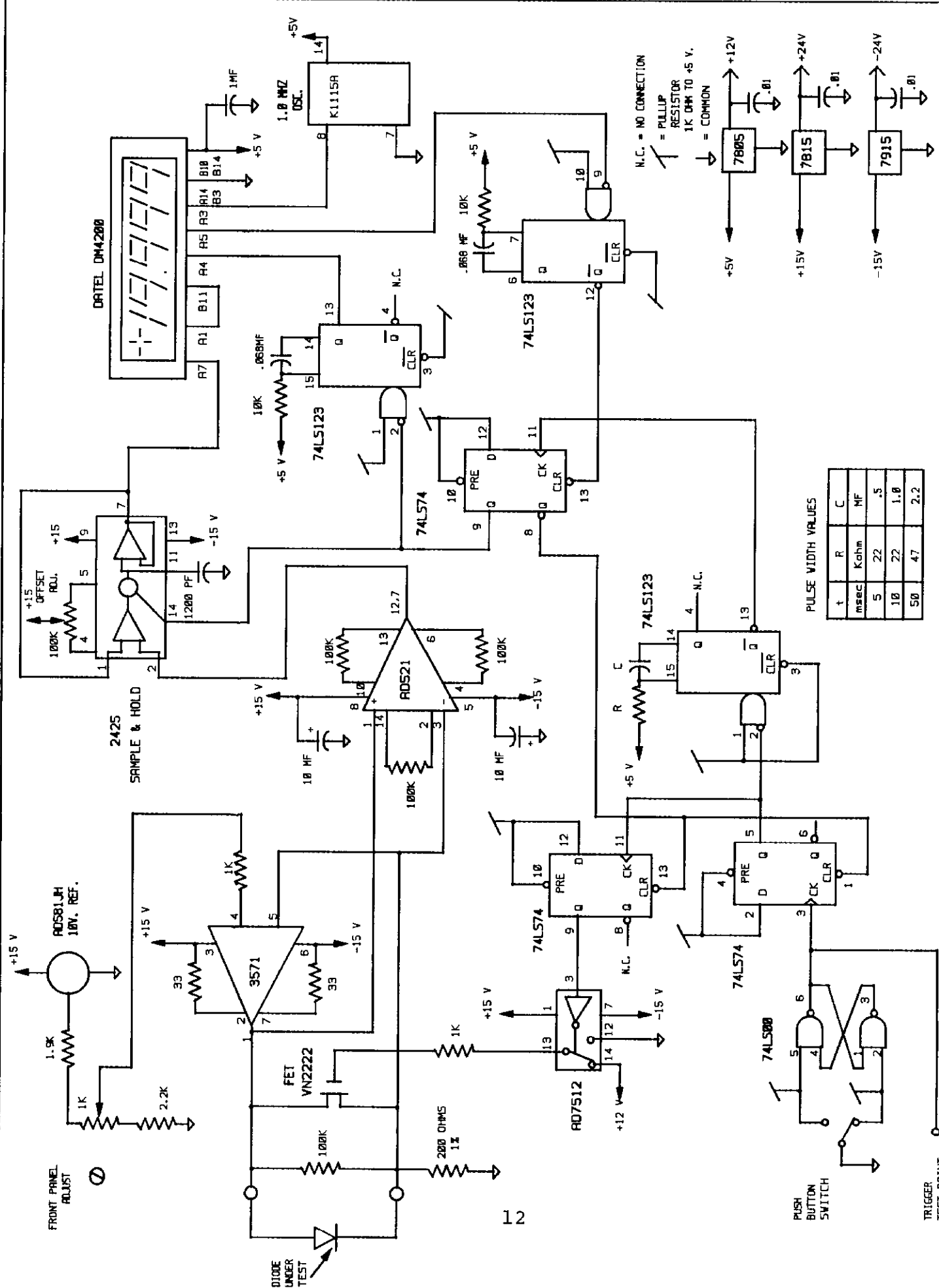


Fig. 3